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OPTIMIZATION OF DRYING AIR TEMPERATURE OF BLACK SOYBEAN UNDER THIN LAYER DRYING

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ABSTRACT

Black soybean is the most important pulse crop of Uttarakhand, India. It is supposed to be very nutritious pulse for the people of Hill region and. Published scientific information about Black soybean is rarely available. Thin layer drying experiments were conducted at five levels of temperature i.e. 32, 40, 50, 60 and 70^{0}C at an air velocity of 0.4m/s and drying characteristics of Black Soybean was investigated to study the optimum drying air temperature and conditions. Page's model was found to fit best at drying temperatures of 40, 50 60 and 70^{0}C. For optimization of drying air temperature mainly shrinkage, cracks, colour, milling recovery and energy consumption per kg of water removal were taken as parameters but shrinkage, colour and cracks in particular were considered as major parameters. The shrinkage was increased from 2.27 to 12.84%. Rapid in the drying temperature range of 32 to 50^{0}C. The colour did not change when the drying temperatures increased from 32 to 50 ^{0}C. There was not significant increase in the cracks development when the drying temperature increased from 32 to 50^{0}C.

KEYWORDS: Black Soybean, Bhatt, Drying of Pulses, Shrinkage, Cracks & Drying Characteristics

Original Article

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INTRODUCTION

Black soybean commonly known as *Bhatt* is traditionally used as pulse grain having high protein content and is similar to soybean, an industrially important crop which has evoked lot of scientific interest. It is a cold climatic crop and is especially grown in the rainfed conditions. Although *Bhatt* is considered as Black Soybean yet its usage differ to a great extent in sense that yellow soybean is mainly used as oilseed crop while Black soybean is used as a pulse crop. After extraction of oil, the cake or defatted flakes of soybean are used for the preparation of different commodities, whereas the Black Soybean is mainly used as pulse grain and is being used since ages. Therefore, Black soybean is something different from soybean to some extent that is why it is used differently and requires separate investigations regarding its properties. Black Soybean contains all three of the macronutrients required for good nutrition; complete protein, carbohydrate and fat, as well as vitamins and minerals, including calcium, folic acid and iron **(Itapattu 2003)**. To utilize these special features and to promote cultivation.

The common practice to utilize Black Soybean is as whole grain. Before consumption, it is either roasted and popped like corn and used as snack in winter or soaked and then cooked as pulse. It is also used as *Dubke (Karhi)* after grinding and boiling. The products of Black Soybean as pulse and Dubke are highly nutritious, and a majority of people prefer. *Lagili*, *Thumri* and *Bhangrail* are the main local varieties of Black Soybean grown in

Himalayan region. The Black soybean crop is dried in the field before harvesting. However, if weather conditions are not favorable, the quality of Black Soybean reduces and need of artificial drying arises. In view of the above mentioned need, the present investigation was under taken with objective to determine thin layer drying characteristics of Black soybean and identification of optimum drying temperature on the basis of cracks, shrinkage, colour, milling recovery and energy consumed during drying.

MATERIALS AND METHODS

ASAE standards 2001 include the ASAE S448 DEC99 standards for thin layer drying. This standard applies specifically to grain and crop that are dried by forced air convection. The experimental set-up developed by **Srivastava (1985)** for studying heat transfer in fixed beds of grain was employed. The set-up consisted of electric motor, blower, air pipe, electric heater, plenum chamber and drying chamber. Plenum Chamber 1m x 1m x 1m was made of brick work with a covered top of 1.5 mm thick mild steel. Two openings, one circular with 300 mm diameter for supplying hot air to the drying chamber and the other square (300 mm × 300 mm) for incoming air to plenum Camber, were provided. The top of the plenum chamber was also covered with 300 mm thick thermocole sheet to prevent heat loss. Drying Chamber, 300 mm diameter and 200 mm long mild steel cylinder was welded to the opening at the top of plenum chamber. An angle iron frame held the drying chamber in place. The angle iron frame rested on the side walls of the plenum chamber. The sample container was held in a G. I. pipe of 155 mm inside diameter by means of a rubber gasket. The complete unit of G. I. pipe and container was mounted on the single iron frame through a wooden board. The sample container was made of aluminum and had an outside diameter of 150 mm. the bottom of the sample container was perforated. All the perforations at the bottom of sample container were of equal size to allow uniform air flow through the grain bed. A 3-phase, star connected, 15 kW, 220 volt electric heater assembly having three segments of 5 kW each, was installed at the air inlet to the plenum chamber. Voltage supply to the heater was controlled through a 3-phase, 470 volt autotransformer. A centrifugal blower driven by a 3-phase, delta connected, 1 hp electric motor was employed to supply air through a G. I. pipe. Two control valves, one to regulate the air flow rate and another to by-pass air flow, were provided in the pipe joining blower and heater to maintain desired air flow rate. Air velocity was measured by using a vane-type anemometer having 10^5 m capacity with a least count of 1 m. Air humidity was calculated by measuring dry bulb and wet bulb temperatures of ambient air with the help of dry and wet bulb thermometer having a range of 0-100^{0}C and a least count of 0.1^0 C. Drying inlet temperature was measured by mercury-in-glass thermometer The ambient air temperature was measured by a thermometer which had a range of 0-100^{0}C and least count of 0.1^0 C. Moisture content of the grain was determined using standard hot air oven method **(ASAE 2001)** and weight of the grain samples was taken before and after drying.

Ninety gram of conditioned Black Soybean having initial moisture content in the vicinity of 25 % (d. b.) was weighed and transferred into the sample container and was placed quickly on the top of the sample holder, The sample was dried to the desired moisture level [10 ± 0.5 %] computed through mass balance. The change in weight was measured at 10 to 30 minutes interval until the sample weight attained a predetermined level, corresponding to 10% moisture content. The process was repeated for samples at ambient/32, 40, 50, 60 and 70^0 C temperatures, the air velocity in all experiments was 0.4 m/s.

Optimization of Drying Air Temperature

The cracks, shrinkage, colour, milling recovery and energy consumed during drying were analyzed at each drying air temperature. Based on above parameters, the optimum drying air temperature was selected.

Shrinkage

The volume of conditioned grain at 25% db was taken by graduated cylinder and then drying was started. After drying the sample to final moisture content of 10% (db), the final volume of dried grain was again taken by graduated cylinder and the shrinkage was calculated as:

$$\text{Shrinkage \%} = \frac{\text{Initial volume of sample-Final volume of sample}}{\text{Initial volume of sample}} \times 100 \tag{1}$$

Cracks

The cracked Black Soybean grains were separated visually. The dried grains (10 g) in triplicate were taken and the cracked Black Soybean grains were separated and weighed. The average crack percentage was taken as mean of samples

$$\text{Crack \%} = \frac{\text{weight of cracked seed in the sample}}{\text{Total weight of the sample}} \times 100 \tag{2}$$

Colour

The colour of the dried Black Soybean at drying air temperature ranging from 32 to 70^{0}C was determined with the help of ten-member observer panel using a 9-point hedonic scale following standard procedure given by the Bureau of Indian Standards.

Milling Recovery

The dried Black Soybean samples having final moisture content 10 ± 0.5 % (d. b.) were subjected to milling. A sample size corresponding to 20 g of Black Soybean was taken. The outputs of milling operation were classified as dehusked dhal, husk, brokens and powder of husk and brokens (chuni). Dehusking was done on 'Satake' laboratory dehusker quantity of 20 g of dried Black Soybean was milled in dehusker for 10 s based on preliminary test. The weight of whole and splitted dhal having the length as ¾ of full length was recorded. The milling recovery was computed as:

$$\text{Milling Recovery (\%)} = \frac{\text{Weight of full dhal}}{\text{Weight of sample}} \times 100 \tag{3}$$

Energy

The energy was calculated by adding the energy consumed by blower of dryer and the energy required to heat the air. The energy required during the drying was estimated by energy required to maintain desired air flow rate i.e. the energy required for blower and energy required to raise the air temperature to the preselected temperature above ambient air temperature i.e. the energy required for heating of air with heaters. The above energy supply were calculated by using complete theoretical approach and the energy losses during drying were considered negligible.

RESULTS AND DISCUSSIONS

Drying of Black Soybean

Drying studies on Black Soybean were carried out in thin layer **(ASAE, 2001**) at ambient temperature (32^0C) and 40, 50, 60 and 70^0C at a fixed air velocity of 0.4 m/s. The values of moisture content (db) taken at 10 to 30 min interval each reported value is an average of three replications. The initial moisture content of grain was about 25% (db), which was reduced to about 10% (db) by thin layer drying. The entire drying took place in falling rate period (Figure 1 and 2). The drying time was longer at lower temperature being 520 minutes at ambient temperature (32^0C) and only 80 minutes at 70^0C.

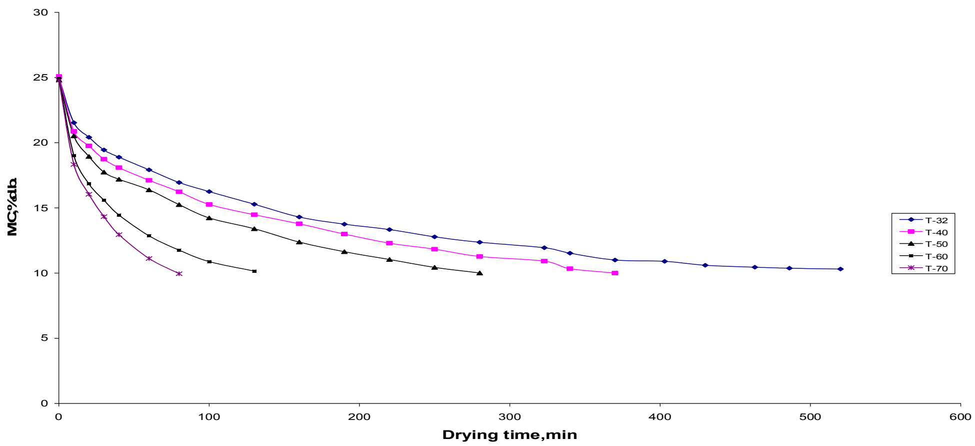

Figure 1: Variation in Moisture Content with Drying Time

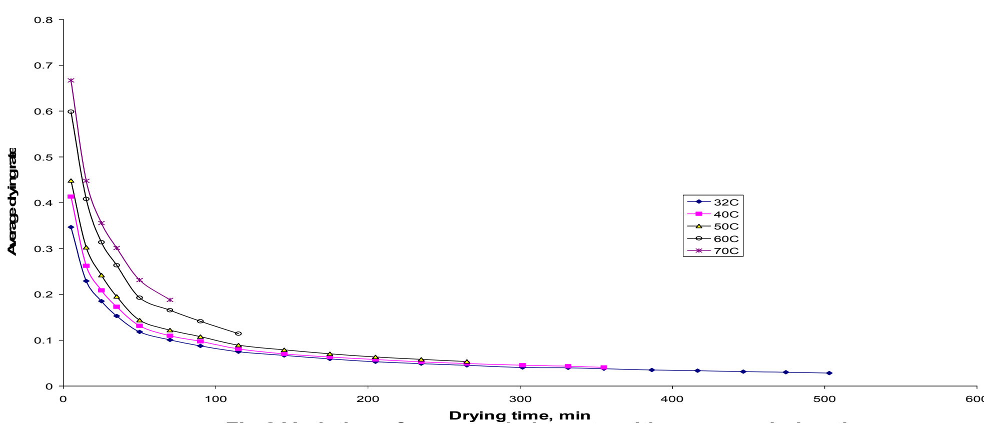

Figure 2: Variation of Average Drying Rate with Average Drying Time

The drying behaviour of Black Soybean is clear from the figures that the drying curves are close to each other at temperatures of 32 to 50^0C and then at temperatures of 60 and 70^0C, but there is a gap in the drying behaviour of *Black Soybean* between the temperature of 50 and 60^0C. Therefore, it appears that something unusual happened between the temperatures of 50 and 60^0C, which lowers the 60^0C drying curve than normal. The drying was faster at higher temperatures, which is expected. The final moisture content of about 10% could be obtained at all temperature. Therefore, the drying could be carried at any of the temperatures to obtain the final moisture content of about 10%. However, other quality parameters will decide the drying air temperature.

Effect of Air Temperature on Drying Rates

- **Overall drying rate:** The overall drying rate was calculated as follows:

Overall drying rate $$(\frac{dM}{dt}) = \frac{M_i - M_F}{\theta} \quad (4)$$

The overall drying rate increased with the increase in temperature varying from 0.0480 m.c. db/min at 32°C to 0.1875 m.c. db./min at 70°C having average drying time of 520 and 80 min respectively.

- **Average drying rate:** The average drying rate was calculated for each experiment as

$$(\frac{\delta M}{\delta T})_{avi} = \frac{M_\theta - M_i}{\theta} \quad (5)$$

The average drying rate represents the cumulative rate of drying from time θ = 0 to any selected dryingθ. As expected, the average rate of drying continuously decreased with the increase in time being faster at higher temperatures.

- **Fitting of the Drying Curves:** The moisture ratio for each drying condition was calculated as

$$MR = \frac{M - M_e}{M_0 - M_e} \quad (6)$$

The following models were selected for testing to determine if any of these models describe the experimental data well.

Logarithmic model **(Hukill, 1947)**

$$MR = A + b\ln t \quad (7)$$

Page's model **(Brooker *et al*., 1974)**

$$MR = e^{-kt^n} \quad (8)$$

Exponential model **(Brooker *et a*l., 1974**)

$$MR = e^{-kt} \quad (9)$$

Generalized exponential model **(Bruce, 1985)**

$$MR = Ae^{-kt} \quad (10)$$

Power law model **(Bruce, 1985)**

$$MR = At^b \quad (11)$$

For fitting the model, the models were first linearised and the linear form of the model is given below;

Logarithmic model

$$MR = A + b \text{ Ln } t \quad (12)$$

Page's model

$$\text{Ln}(-\text{Ln MR}) = \text{Ln}(+k) + n\,\text{Ln}\,t \tag{13}$$

Exponential model

$$\text{Ln MR} = -kt \tag{14}$$

Generalized exponential model

$$\text{Ln MR} = \text{Ln}\,A - kt \tag{15}$$

Power law model

$$\text{Ln MR} = \text{Ln}\,A + b\,\text{Ln}\,t \tag{16}$$

The constants of the models were determined at each temperature individually and the constants along with r^2, SEE, RSS, E_{90} and E_{50} for the models, considered in this study. The best model was selected based on all the above five parameters. The fitted model should have high r^2 and lower values of other parameters like SEE, RSS, E_{90} and $E_{50.}$ Considering all these parameters the **Page's (Brooker *et al*., 1974)** model could describe the experimental data most closely and was selected for analyzing the drying behaviour of Black Soybean. The page's model has two constants, k and n The values of k and n were calculated for each temperature separately. An attempt was made to use average value of n for all temperatures and recalculate the values of drying constant k. The drying constant k had a unique behaviour with the temperature in the sense that the plot of recalculated value of k drying constant and $1/T_{abs}$ decreased up to 50^0 C and then increased. However, this recalculated k could be related to $1/T_{abs}$ by the following equation

$$k = k_0 \exp(-E/T_{abs}) \tag{17}$$

The individual values of constant n at different temperatures were plotted against absolute values of temperature (Figure 3). The curve showed a non-systematic variation of n with absolute temperature. The values of n decreased up to 50 ^{0}C and then increased. An equation of the following form could describe the variation of n with absolute temperature:

$$n = 0.0004T^2_{abs} - 0.2837T_{abs} + 47.148 \tag{18}$$

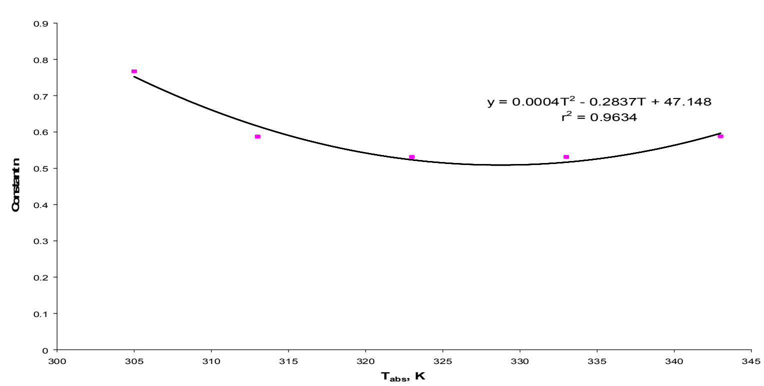

Figure 3: Variation in n with Absolute Drying Air Temperature, Page's Model

The relationship had a correlation coefficient of determination (r^2) of 0.9634. Since taking an average value of n for all the temperature in the drying range disturbed the values of constant k, the approach of taking average value of n was abandoned and individual values of n at every temperature was recommended for use. A plot of Ln k (drying constant)

Figure 4 with individual value at different temperature versus 1/ T_{abs} revealed that the values of k could be related to T_{abs} by following equation

$$k=835.99\exp(-E/T_{abs}) \quad (19)$$

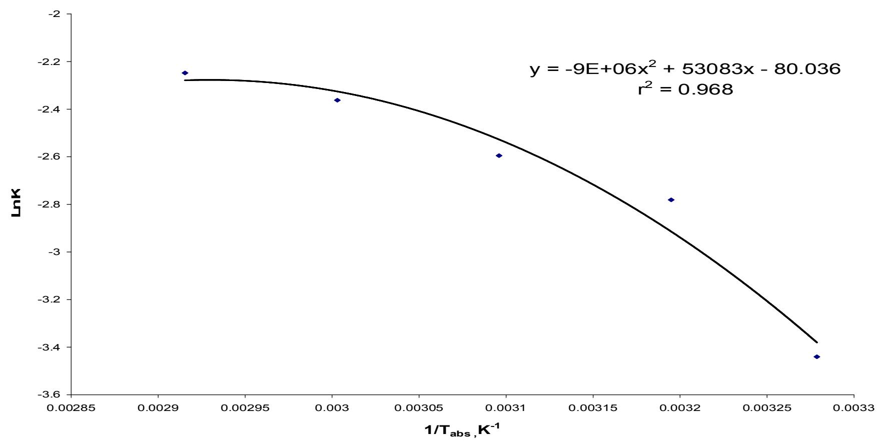

Figure 4: Variation in Ln K with 1/T^{abs}

The above equation had r^2 and SEE values 0.8824 and 0.1861 respectively. The curve at ambient temperature (32^{0}C) is not close to observed values in the sense that r^2 of 0.9236 was observed at this temperature compared to above 0.99 at all other temperatures. This fact has reflected in the curve of ambient temperature (32^{0}C) drying. Moreover, for calculation of MR ratio at ambient temperature, the plotted value of equilibrium moisture content was used instead of the predicted value because the predicted value was 10.814 and observed value was 10.3. The use of predicted value of equilibrium moisture content at this temperature resulted in negative value of MR, which was not accepted. The use of observed value of equilibrium moisture content did not pose any problem and therefore was accepted. At all other temperatures, the values of equilibrium moisture content predicted by modified Oswin model at drying conditions were used.

DRYING PARAMETERS

Shrinkage

The shrinkage characteristics of Black Soybean dried at different temperature and average a three replications. The shrinkage, on drying from about 25 to 10%, increased non- linearly from 2.27% to 14.29% (Figure 5) when the drying temperatures increased from 32 to 70^{0}C. The shrinkage was rapid in the drying temperature range of 32 to 50^{0}C in the sense that it increased from 2.27 to 12.84%.The shrinkage in Black Soybean could be described by the following relation:

$$S = -34.449+1.531\,t-0.012\,t^2 \quad (20)$$

The above relationship had r^2 value of 0.9904. After 50^0 C, the increase in shrinkage was small, less than 1.5 %, up to drying temperature of 70^0 C.

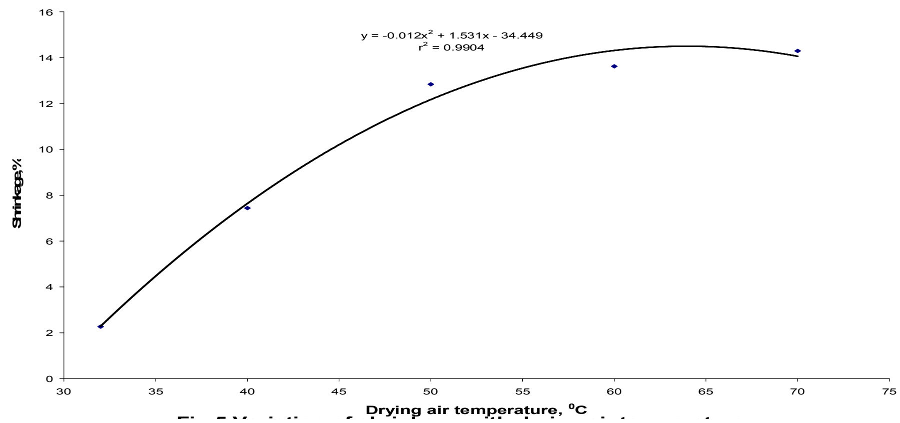

Figure 5: Variation of Shrinkage with Drying Air Temperature

Crack

The data on the cracks developed in the Black Soybean are the average of three replications showed non-linearly increased from 8.53 % to 36.63 % as drying temperatures increased from 32 to 70^{0}C. There was not much increase in the cracks development when the drying temperature increased from 32 to 50^{0}C. At these temperatures, the cracks increased by less than 1%. However, there was sudden increase in the cracks at temperature about 50^{0}C, which were 31.30% at 60^{0}C. Therefore, as the temperature increased from 50 to 60^{0}C, there was an increase of about 22% cracks. On further increasing in temperature to 70^{0}C, the cracks increased only by about 5%. The phenomenon of crack development is shown in Figure 6 and could be described by the following equation and had r^2 value of 0.8977.

$$C_r = 30.29-1.4146t+0.022t^2 \tag{21}$$

Colour

The colour values obtained through sensory evaluation each value of colour is an average of 30 replications. The colour did not change when the drying temperatures increased from 32 to 50 ^{0}C. The first sign of change in colour score was noticed when drying air temperature increased from 50 to 60^{0}C. The colour variation could be described by the following equation and had r^2 value of 0.9833.

$$C_o = 5.3015+0.0889t-0.0011t^2 \tag{22}$$

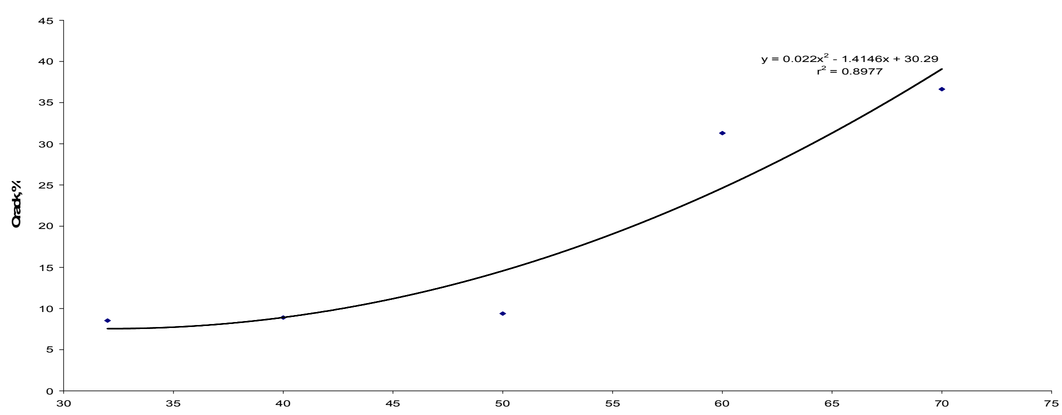

Figure 6: Effect of Drying Air Temperature on Cracks

Milling Recovery

Milling recovery of Black Soybean varied from 71.58 to 78.82%. The milling recovery non-linearly increased when the drying air temperature increased from 32 to 70 ^{0}C. The values of milling recovery are also shown in Figure 7. There was rapid increase in milling recovery when the temperature increased from 32 to 40 ^{0}C and then the increase was somewhat slower. The total increase in milling recovery was less than 1.6% when temperatures increased from of 40 to 70 ^{0}C whereas it increased by more than 5% for 8 ^{0}C rise in temperature, from 32 to 40 ^{0}C.The relationship could be described by following equation and had r^2 value of 0.8549.

$$M_r = 50.446+0.9315t-0.0076t^2 \quad (23)$$

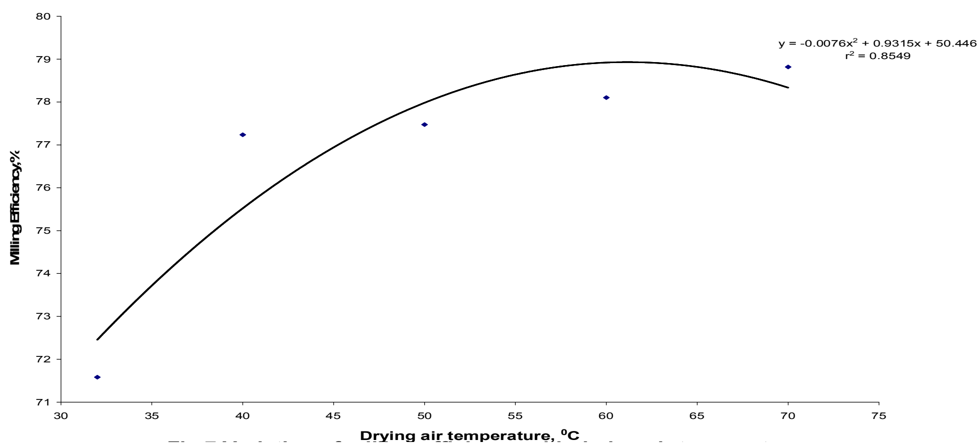

Figure 7: Variation of Milling Efficiency with Drying Air Temperature

Energy

The energy for heating and blowing air linearly decreased as the drying air temperature increased (Figure 8). The maximum value of energy is 80.27 KWH and minimum value is 16.11 KWH per kg of water removal. The lower value of energy at higher temperature are mainly the reflection of faster drying as the time required to dry the grain at 70^{0}C was only 80 minutes against 520 minutes at 32^{0}C. The Figure 8 shows the energy supply values at different drying air temperatures. The energy supplied for Black Soybean drying could be described by the following equation and had r^2 value of 0.9921:

$$E_y = 135.01-1.739t \quad (24)$$

It is obvious that the cracks increased and colour decreased as air temperature reached beyond 50^{0}C. Therefore, 50^{0}C drying air temperature was considered the maximum temperature for grain storage of black soybean. This finding is in agreement with the finding of past investigators who found that 50^{0}C is the optimum temperature of drying of soybean **(Kaushal, 1979).**

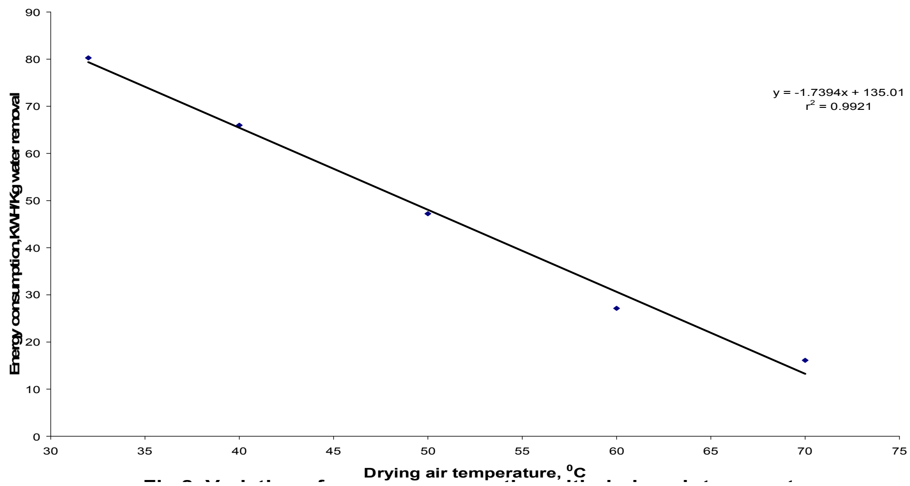

Figure 8: Variation of Energy Consumption with Drying Air Temperature

CONCLUSIONS

Among all the model tested on drying data the Page's model was found to fit best at drying temperatures of 40, 50 60 and 70^{0}C. However at 32^{0}C, logarithmic model performed better on the basis of r^2, SEE, RSS, E_{90} and E_{50}. The 50^{0}C drying air temperature was found the maximum air-drying temperature on beyond this temperature, cracks increased drastically which may increase storage losses. The relation between drying constant and temperature can be expressed by the Arrhenius type equation.

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